ULTRASONIC CHARACTERIZATION OF CEMENT AND CONCRETE

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INTRODUCTION

Ultrasonic velocity measurements are used to control the quality of fresh Concrete and to monitor the concrete mixtures during hardening or curing process. The goal of this research is to determine the time required for a given mixture of Concrete to be hard enough for form removal in a construction site. Currently the concrete form removal time is not accurately known. The early removals of the concrete forms results in weaker concrete and the late removal of the concrete forms prolong the construction time. The shear and rigidity moduli of freshly mixed concrete increases with time and this change can be monitored by measuring the ultrasonic velocity in the concrete as a function of time. In this paper we investigate the evolution of ultrasonic pulse wave velocity as a function of time in the concrete mixtures, with different water to cement ratio. The results obtained can be used to predict the setting time of concrete and also to control the quality of the concrete in the construction industry. The curing process is a series of chemical reactions by which the concrete mixture, when not stirred, gradually increases its viscosity and hardens with time until it becomes completely crystallized and rigid. In the construction industry, knowledge of the setting-time of the concrete for form removal or for the addition of a new edifice is crucial for speeding up the construction. Although there are published guidelines such as tables from the American Concrete Institute, currently this time interval cannot be accurately predicted. It depends on the uncontrollable parameters such as ambient temperature and humidity, among other factors.

TECHNICAL SUMMARY

The goal of this research is to predict final quality, setting-time and mechanical strength of a fresh concrete. Ultrasonic sensors are used to monitor the curing of fresh concrete and to follow-up, in real-time, the change in its rigidity and stiffness with time, in order to predict the setting time and the readiness of the concrete for overlay construction. The technical approach consists of monitoring, by ultrasonic sensors, the elastic wave propagation in a concrete mixture, a multiphase media, which in the case of concrete mixture are mainly cement, water, air bubbles and sand. The theory of elastic waves in two-phase granular materials, for long-wavelengths and when the grain contact effects are not considered, is described by Biot's equations [1]. However, this theory needs to be modified when the wavelength become comparable to the grain size [2]. This modification includes the consideration of intergranular contact effects [3], [4].

The wave velocity in a given granular material is a function of its stiffness and rigidity. The stiffness can be related to Young's modulus. As a given cement mixture cure, Young's modulus increases with time. Therefore the ultrasonic longitudinal wave velocity should also increase with time. Experimental results obtained in the laboratory [5] for a thin slab of cement are shown in Figures 1. and 2. In these figures are shown the increase in longitudinal velocity and shear wave velocity with time (0 to 48 hours), for water to cement ratios of 30%, 40%, 50% and 60%.

The gradual increase in rigidity of fresh concrete with time results in faster wave velocity. A unique profile of wave velocity versus time is obtained for each cement mixture. This property can be used to predict the subsequent evolution of a concrete mixture with time and its final mechanical strength after curing.

Experimental approach for this investigation consists of attaching to the concrete the ultrasonic transducers of center frequencies 500 kHz, to monitor the hardening of a slab of fresh white cement. Experiments in laboratory with concrete mixtures are carried out with different water to cement ratios. From the data collected every twenty minutes, with the aid of a computer, ultrasonic wave velocity profiles as a function of time is obtained[3]. Figure 3 shows the correlation between dynamic Young's Modulus and the Resistance under compression for mortar at T = 25°. Figure 4 shows the variation of thermal flux, heat released and thermal conductivity of mortar as a function of time.

Critical Exponent for Percolation Threshold

The degree of connectivity (E/E^*) increases exponentially with the degree of reaction, $\alpha = dH/dt$.

α is measured by calorimeter from the released heat H.

$$\frac{E}{E^*} = \frac{[\mathbf{Exp}\,(10\,\boldsymbol{\alpha} - 6.4)]}{\left(\frac{w}{c}\right)^2} \tag{1}$$

The Beginning of Setting and the Threshold of Percolation

The number of links forming is proportional to the number of connections already made. For a given initial value of water to cement ratio (w/c) it is possible to predict the degree of hydration corresponding to a complete

Table 1. Time required for the appearance of shear wave and for the occurrence of a minimum in compression wave speed, with the critical exponents, for two types of cement pastes and for water to cement ratios of 40% and 35%.

Cement Paste Type	Minimum in Compression Wave speed	Percolation Time t_c	Time for the Detection of first Shear Wave	Critical Exponent $\sqrt{}$
PCCB9402 w / c = 40% T = 25 °C	145 ± 15 MIN	160 ±15 MIN	195 ± 15 MIN	2.15
PCCB9402 w / c = 35% T = 25 °C	105 ± 15 MIN	120 ±15 MIN	155 ±15 MIN	2.03
PCCB9401 w / c = 40% T = 25 °C	105 ± 15 MIN	135 ±15 MIN	210 ± 15 MIN	1.92
PCCB9401 w / c = 34% T = 25 °C	90 ± 15 MIN	125 ±15 MIN	165 ± 15 MIN	2.13

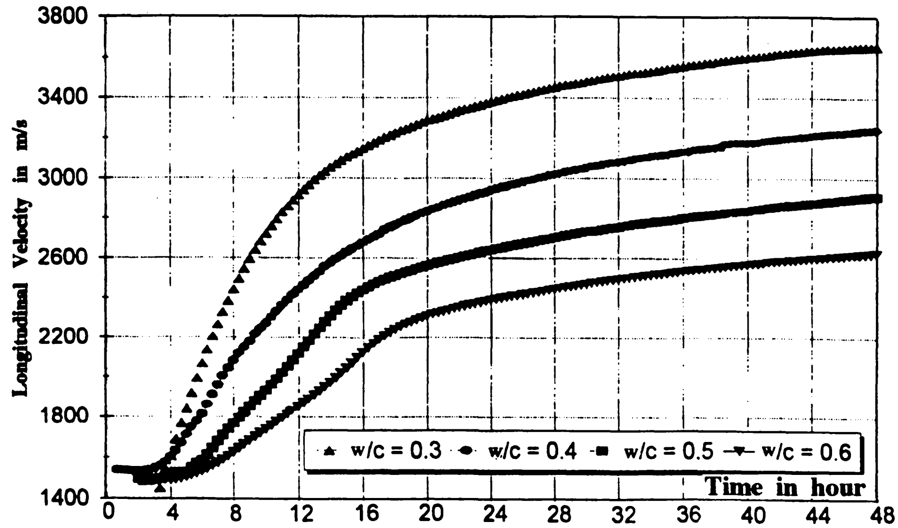

Figure 1. Experimental data points for the variation of longitudinal wave velocity versus time, in white cement paste, for water to cement ratios of 30%, 40%, 50% and 60%.

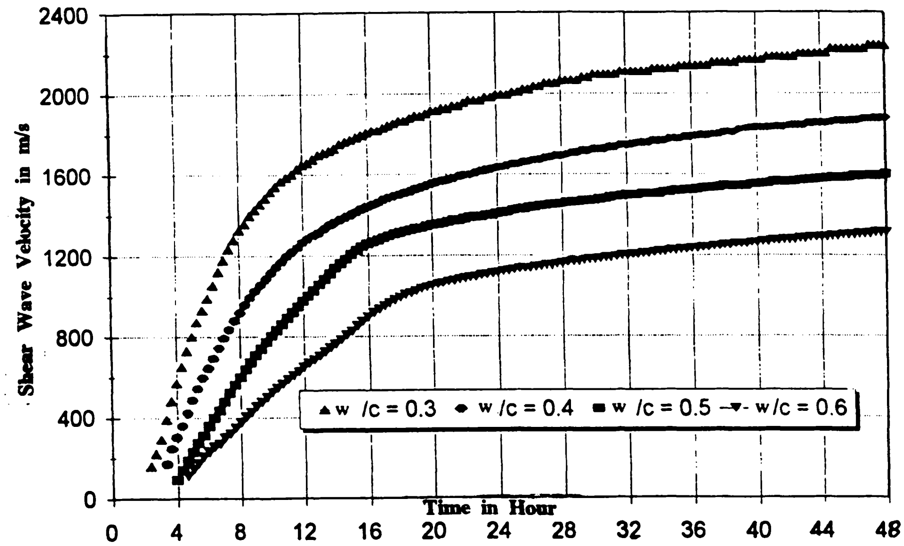

Figure 2. Experimental values for the variation of ultrasonic shear wave velocity versus time, in white cement paste having the water to cement ratios of 30%, 40%, 50% and 60%.

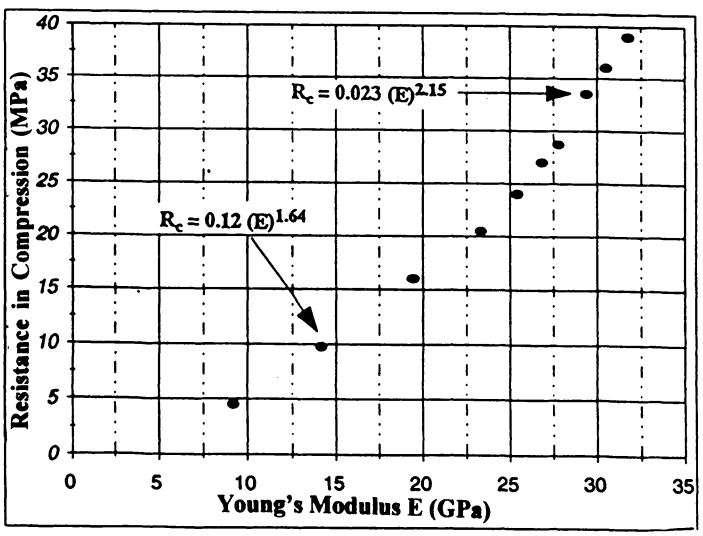

Figure 3. Correlation between dynamic Young's modulus and resistance to compression of the concrete mortar B35, at T = 25°.

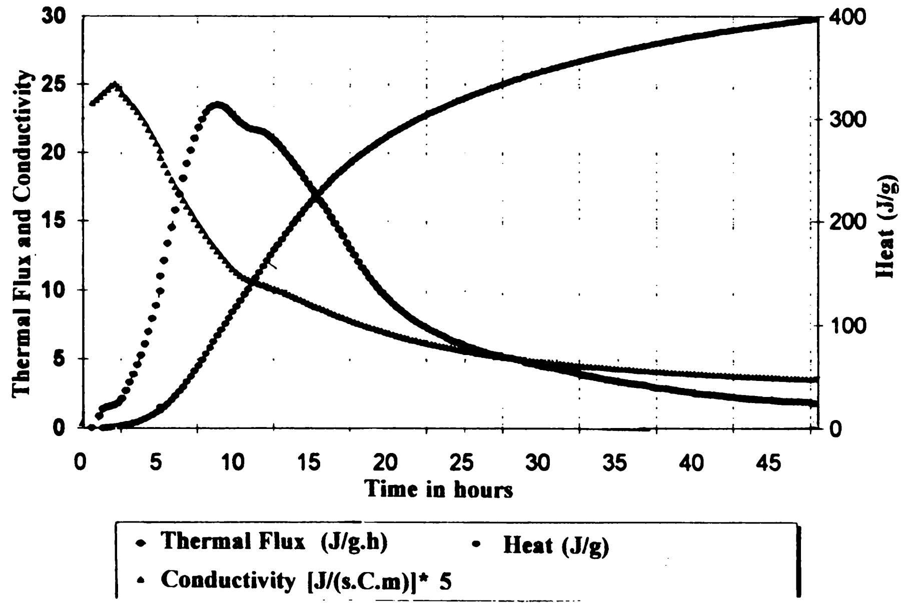

Figure 4. Experimental values showing the variation of thermal flux, heat released and thermal conductivity of concrete mortar B35 as a function of time, in hours.

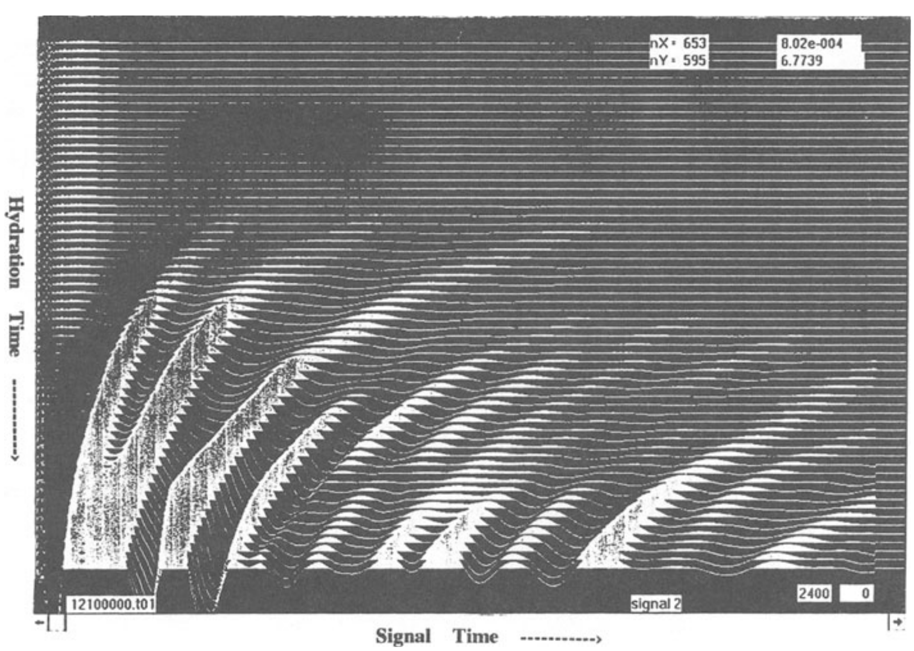

Figure 5. Water-fall plot of shear wave signals, received after transmission through 2.5 cm thick sample of freshly made cement paste, showing the delayed appearance of the signal and the decrease in arrival time with hydration time. *(Note: time increases from top to the bottom on the vertical axis).*

setting. The change in shear modulus, G, as a function of time, t, and percolation time, t_c, is

$$G = G_0' (t - t_c)^{\nu'} \tag{2}$$

The critical exponent, ν', for different cement paste and w/c ratios, is given in Table 1. Figure 5 shows the water-fall plot of shear wave signals, received after transmission through 2.5 cm thick sample of freshly made white cement paste, notice the delayed appearance of the signal corresponding to the threshold of percolation.

<u>Composition of Portland cement</u>: which is obtained by Calcination at 1500 °C of calcite (80%) and clay (20%). The clinker formed is grounded to fine particles (20 μm). Clinker Composition:_Notations: C = Ca O, S = Si O_2, A = Al_2O_3 F = Fe_2O_3. Tricalcium Silicate C_3 S (60 %), Dicalcium Silicate C_2 S (20 %), Aluminate C_3 A (10 %), Tetracalcium Ferro Aluminate C_4 AF (10 %).

CONCLUSION

The goal of this investigation is to develop a sensor measurement technique for fresh concrete applicable to the construction sites. Measurements made with different cement mixtures show that it is possible to predict the time required to reach a particular value of hardness and the final mechanical strength of a given cement mixture. These results will be used to develop a measurement technique and design sensors with appropriate electronics, for potential field use and transfer to the construction industry.

REFERENCES

1. M. A. Biot, *J. Acoust. Soc. Am.* 28, pp. 168 and 179, 1956.
2. H. M. Tavossi, B. R. Tittmann and F. Cohen-Tenoudji, "Ultrasonic wave dispersion and attenuation in fluid filled porous media", *Proceedings of The QNDE Conference*, San Diego. CA., 1997.
3. H. M. Tavossi and B. R. Tittmann, "Ultrasonic Wave Dispersion and Attenuation in Model of Porous Ground and Sediment", *Proceedings of Sixth Conf. on Acoustic Emission/Microseismic Act. in Geo. Structures & Mat., Series on Rock and Soil Mech.* Vol. 21, pp. 121-141 Tras Tech Publication, 1998.
4. H. M. Tavossi and B. R. Tittmann, "Ultrasonic Characterization of Sediment Model Media", *Proceedings 14th World Conf. on NDT,* Oxford & IBH Pub. Co. New Delhi, India, pp 2169-2173. 1996.
5. A. Boumiz, F. Cohen-Tenoudji and C. Vernet, "Determination of Elastic Moduli of Cement Pastes and Mortars During Setting and Hardening by Ultrasonic Measurements", *Abstract QNDE Conference* , San Diego, CA., 1997.